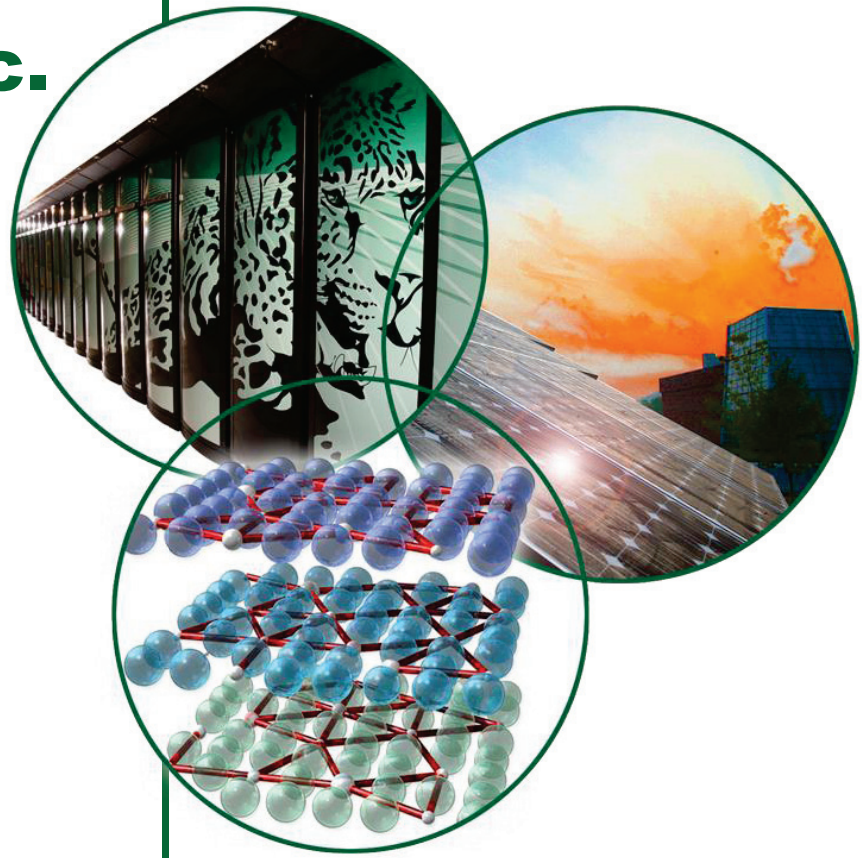
Model and Beam Based Setup Procedures for a High Power Hadron Superconducting Linac.



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U.S. DEPARTMENT OF ENERGY

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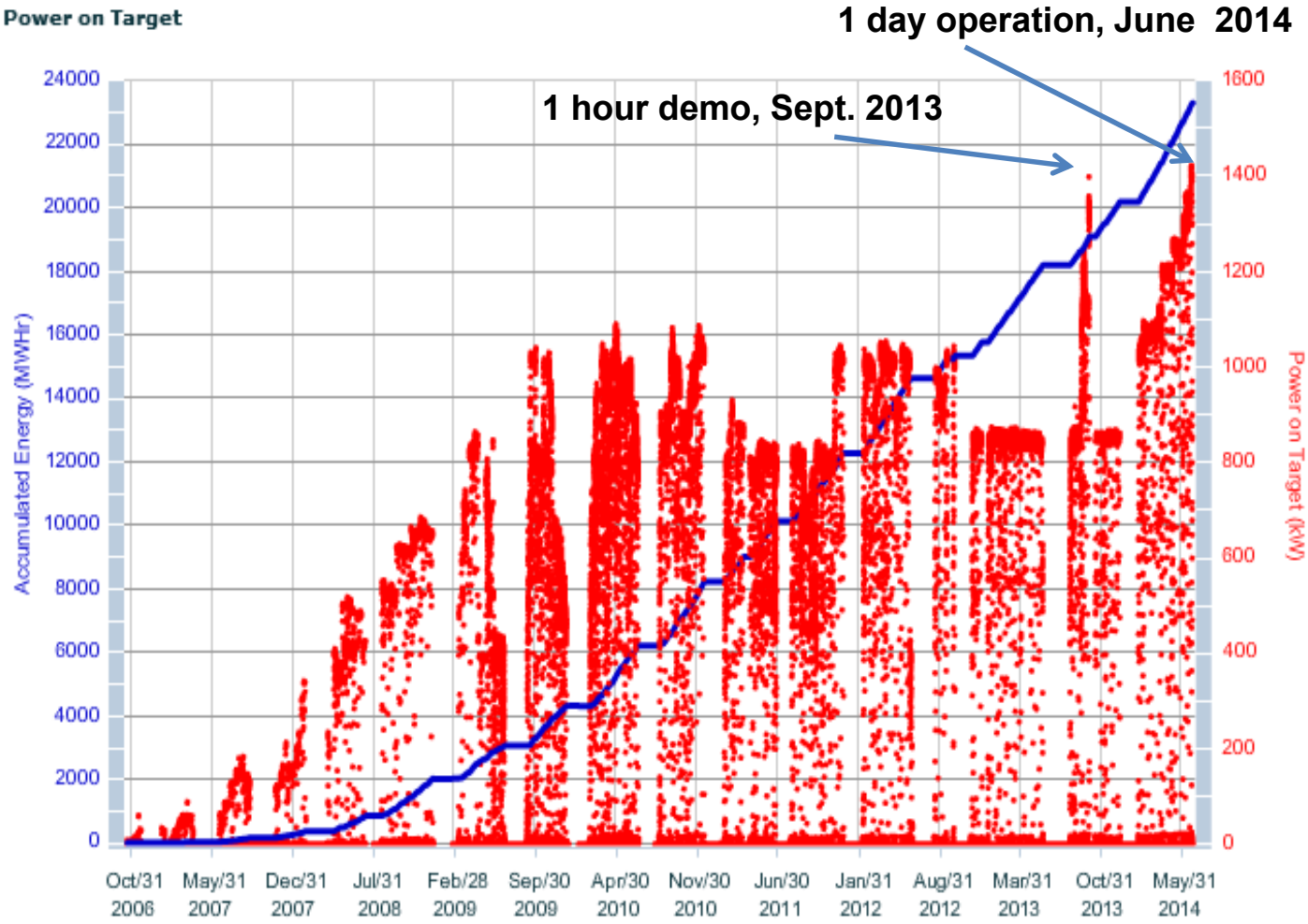
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

- Spallation Neutron Source (SNS) – 1.4 MW!
- Introduction
  - SNS Superconducting Linac (SCL) Overview
  - Beam Loss Mechanism in SNS Superconducting Linac
- SNS SCL Setup Procedures
  - SCL Cavities' Phases Setup – How Fast, Accuracy, and Results
  - Initial Longitudinal Twiss Parameters
  - Initial Transverse Twiss Parameters
  - Matching Considerations
- Future Works and Conclusions

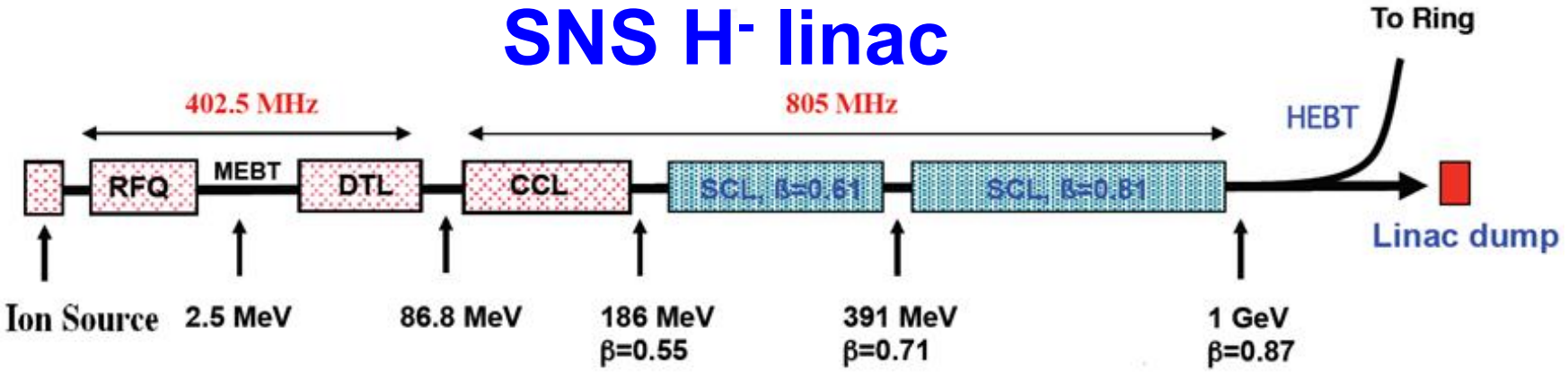
1.4 MW Beam Power at SNS



- First neutron production at 1.4 MW: June 29, 2014
  - Sustained power increase during the 2014 run, increasing power from 1.1 MW to 1.4 MW

SNS Linac Structure

SNS H$^-$ linac



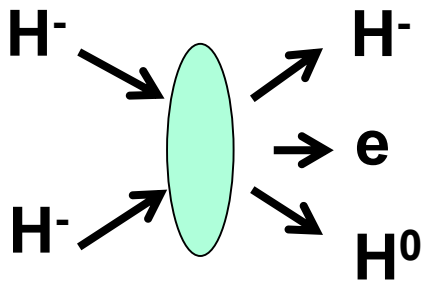
Length: 330 m (Superconducting part 230 m)

Production parameters:
Peak current: 38 mA
Repetition rate: 60 Hz
Macro-pulse length: 1 ms
Final Energy: 940 MeV (1000 MeV design)
Average power: 1.4 MW

SCL Diagnostics:
BPM - Beam Position and Phase Monitors through the whole linac
LW - Laser Wire stations, 9 stations in SCL – Transverse Profiles

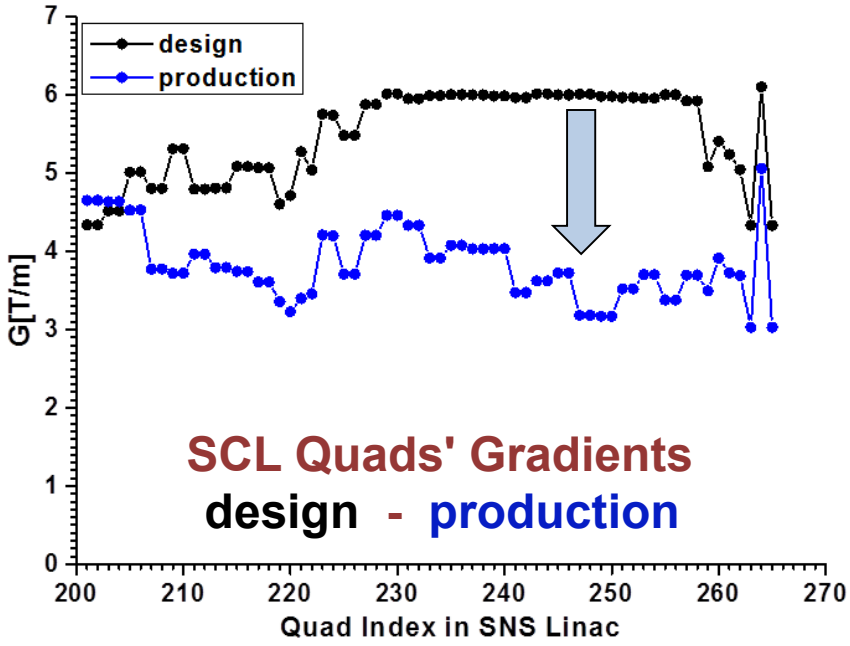
Beam Loss in the SCL

- According to the design the SCL should be loss-free
  - » Beam pipe aperture is about 10 times beam rms size
  - » Vacuum is one order of magnitude better than in the warm part
  - » Residual gas is H^0 instead of nitrogen
- Not really! The cause is the Intra Beam Stripping (IBSt)
- *Replacement H^- by protons reduces beam loss by 30 times*



But we still need H^- !

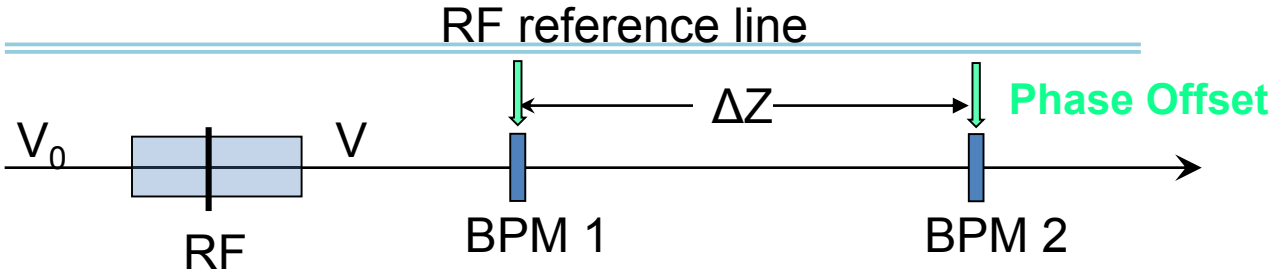
- Loss and activation were reduced by reducing the SCL quad gradients and making beam bigger – counterintuitive
- Now the SNS power is not limited by SCL loss and activation
- We have balance between reduced IBSt and rising beam loss because of the beam size
- Beam loss has been reduced, but we want to reduce it further based on the
  - known loss mechanism
  - knowledge of the beam optics



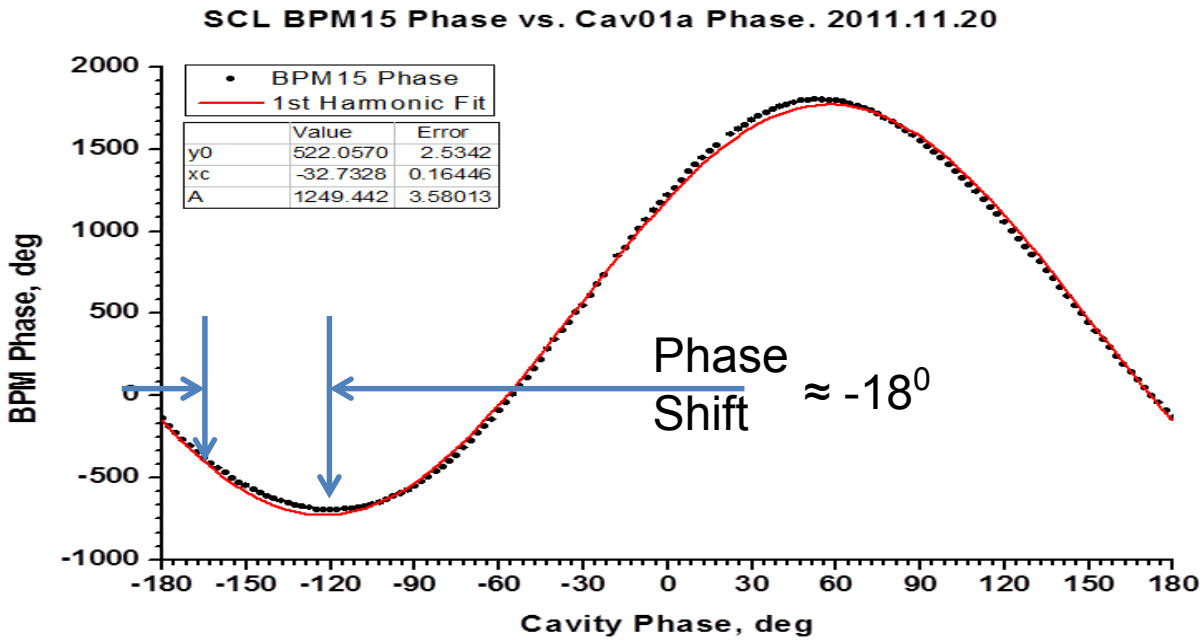
SNS SCL Setup Procedures

- **Existing procedures for SCL Linac:**
  - RF Cavities:
    - Amplitudes are fixed.
    - Synchronous phase for all SCL cavities are -18^0 .
    - Phases are setup by phase scans
  - Quads - setup field gradients (historic data + empirical loss reduction)
  - The final step includes tweaking the warm linac parameters
- **For model based tuning we need the initial Twiss parameters**
  - Measurement of Longitudinal Twiss based on BPMs' signals
  - Transverse Twiss – Laser Wire Stations
  - Results
- **Considerations for Model based matching**

SCL RF Cavities Phase Scans



- RF Phase Setup by Time Of Flight measurements
- No model involved, only a "sine"-like curve analysis
- No need for BPM timing calibration before the scan

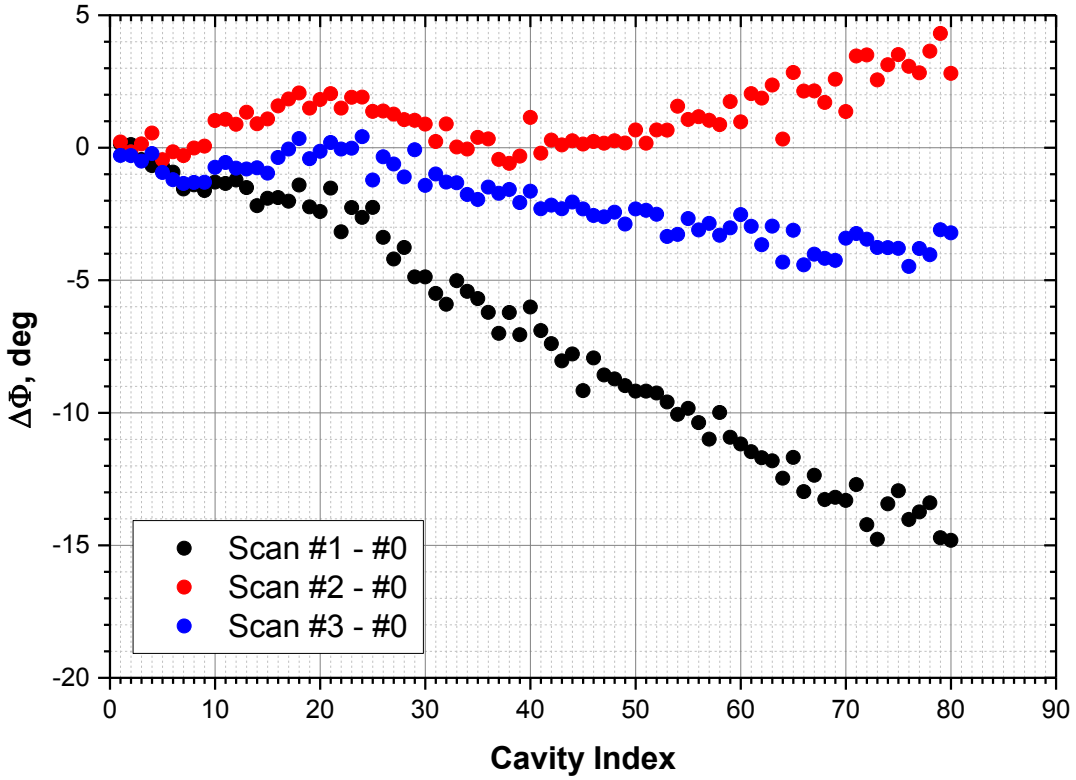


SNS SCL Phase Scan Application Progress

SCL phase scan analysis is a part of an integrated application for SCL tuning.

- During the analysis of the scans:
  - Perform the timing calibration of all BPMs (using ring)
  - Find the parameters of the model for all SCL cavities
- Synchronous phase accuracy is about 1.0^0
- Non-destructive phase scan.
- Automation: from 6 hours -> 20 minutes for 81 SCL cavities

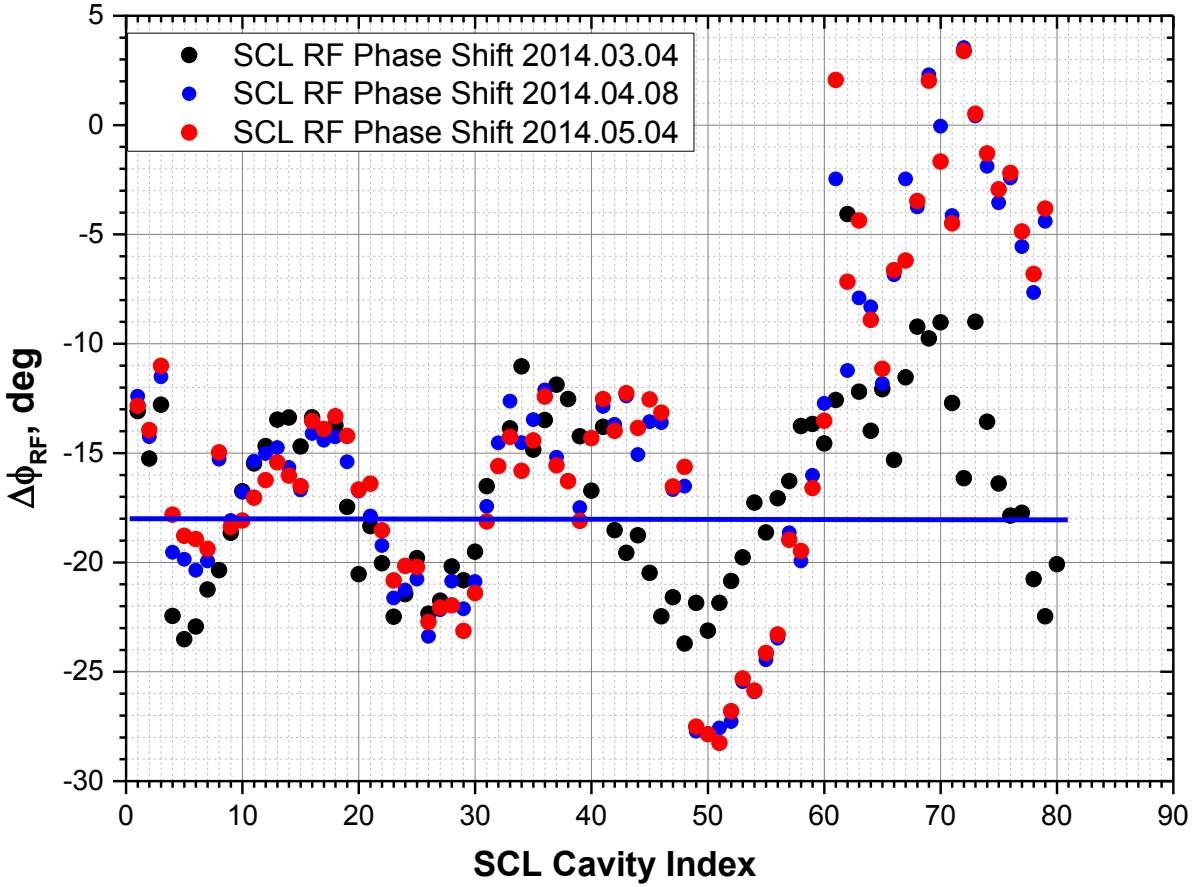
“Scan to Scan” Stability



- 4 back-to-back scans
- All results are different
- No differences in beam loss
- All are a good start for tuning

- ❑ We do not know the cause yet.
- ❑ Based on the time scale, we believe that it is related to the tunnel temperature oscillation.
- ❑ The effect has zero effect on our tuning strategy.

SCL Cav. Synchronous Phases – Production Values for Low Beam Loss



The SNS Linac was tuned up in Feb. 2014.

Phase shifts -18^0 for all SCL RF cavities.

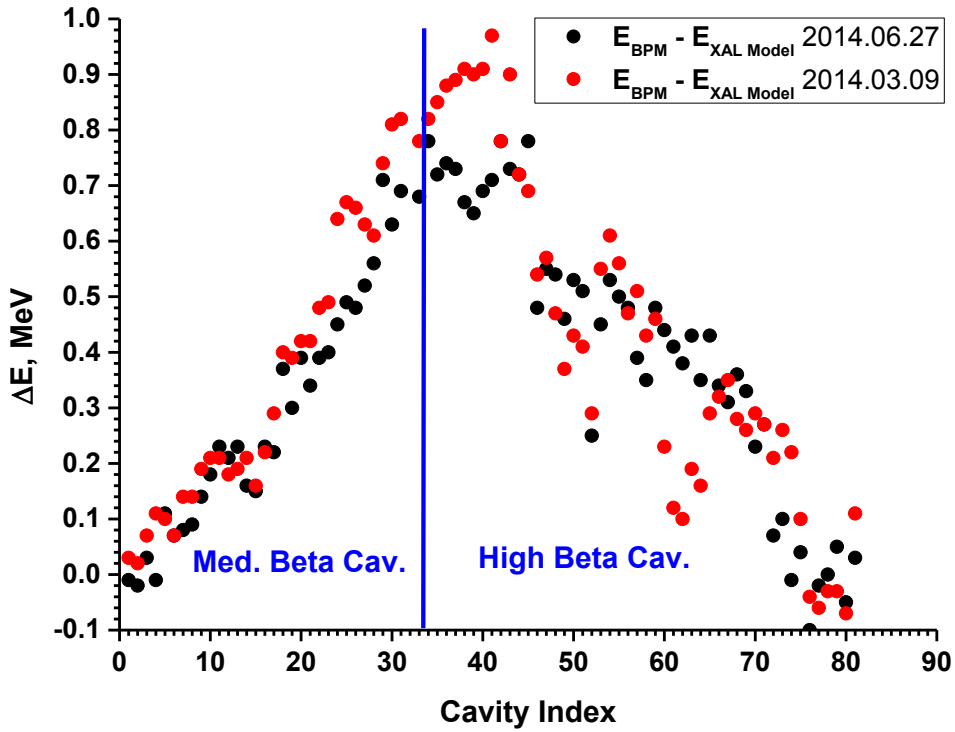
On the left are the measured production synchronous phases.

We are far from design.

Beam loss is good.

Clearly, there is a structure.

Energy Tracking: XAL Model vs. BPM

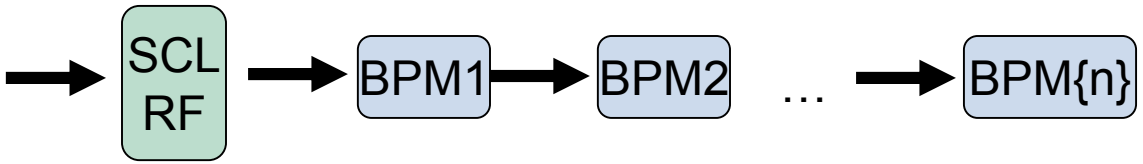


- Model parameters of each RF cavity are from scan data
- After that they all combined into one lattice
- Track energy through this lattice
- Compare to the BPMs data

May be our XAL model for cavities is not perfect, and we have to pay attention.

That is experiment results vs. one particle model tracking!
A good case for the code benchmark!

Longitudinal Twiss Analysis



Amplitudes of BPMs as byproduct of phase scans

In the case of Gaussian distribution of the longitudinal density:

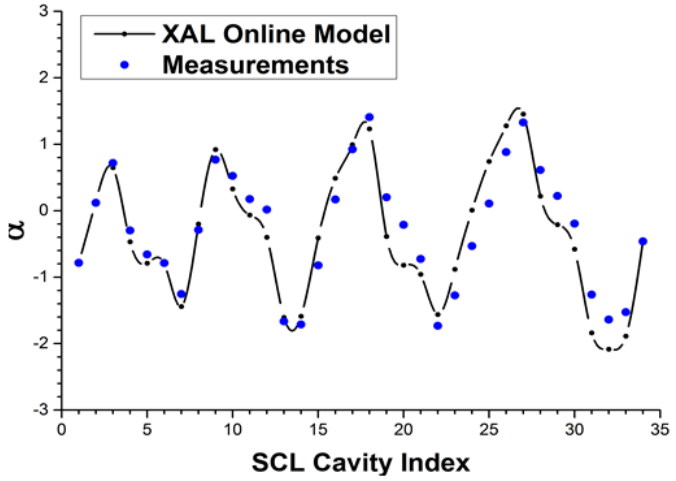
$$U_{BPM}(\sigma_\varphi) = A_0 \cdot \exp\left(-2 \cdot \pi^2 \cdot \left(\frac{\sigma_\varphi}{360^0}\right)^2\right)$$

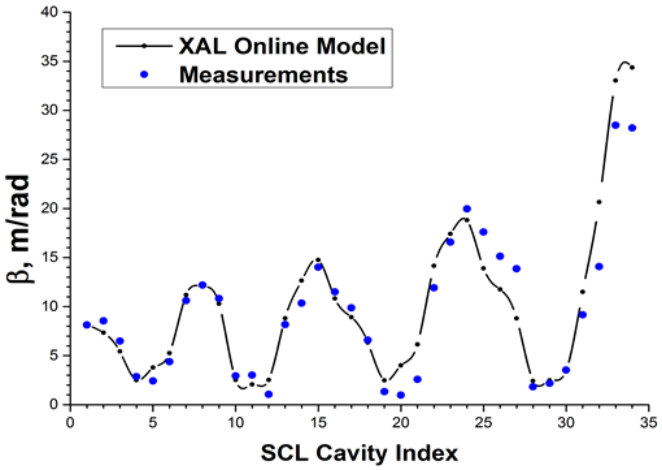
σ_φ **- Longitudinal RMS bunch size in deg.**

- **We use the sum signal of BPMs'**
- **Using the model we get the longitudinal Twiss at the entrance of the cavity**
- **Each cavity and downstream BPMs are "Bunch longitudinal RMS size" monitors**
- **The approach is working only for "Gaussian"-like distributions**

A. Shishlo, A. Aleksandrov, Phys. Rev. ST Accel. and Beams 16, 062801 (2013).

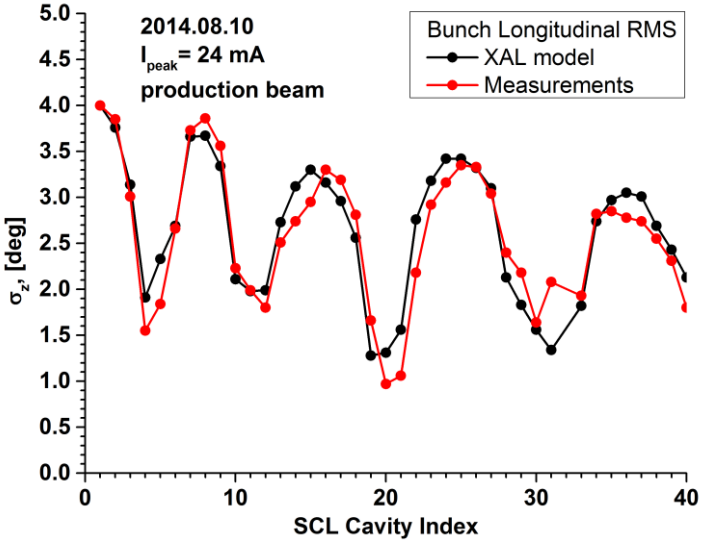
Results of "Z" Twiss Analysis





Year: 2013

Longitudinal Twiss
Peak current 7 mA

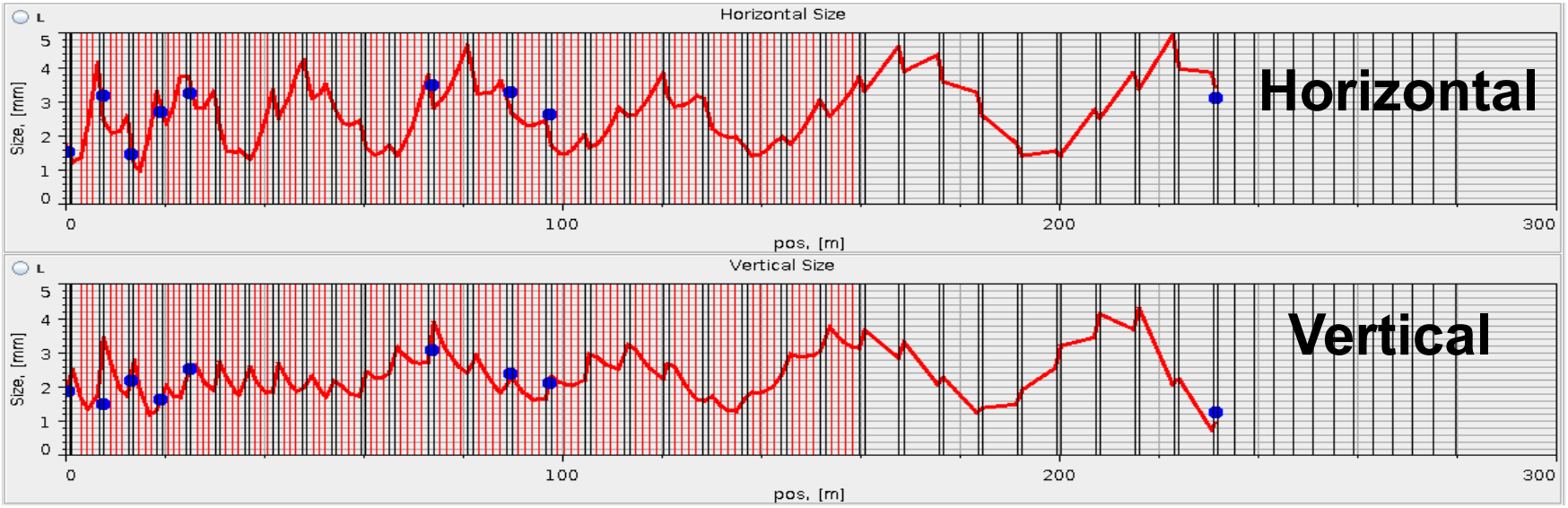


2014.08.10

Longitudinal beam size
Peak current 24 mA
Production beam

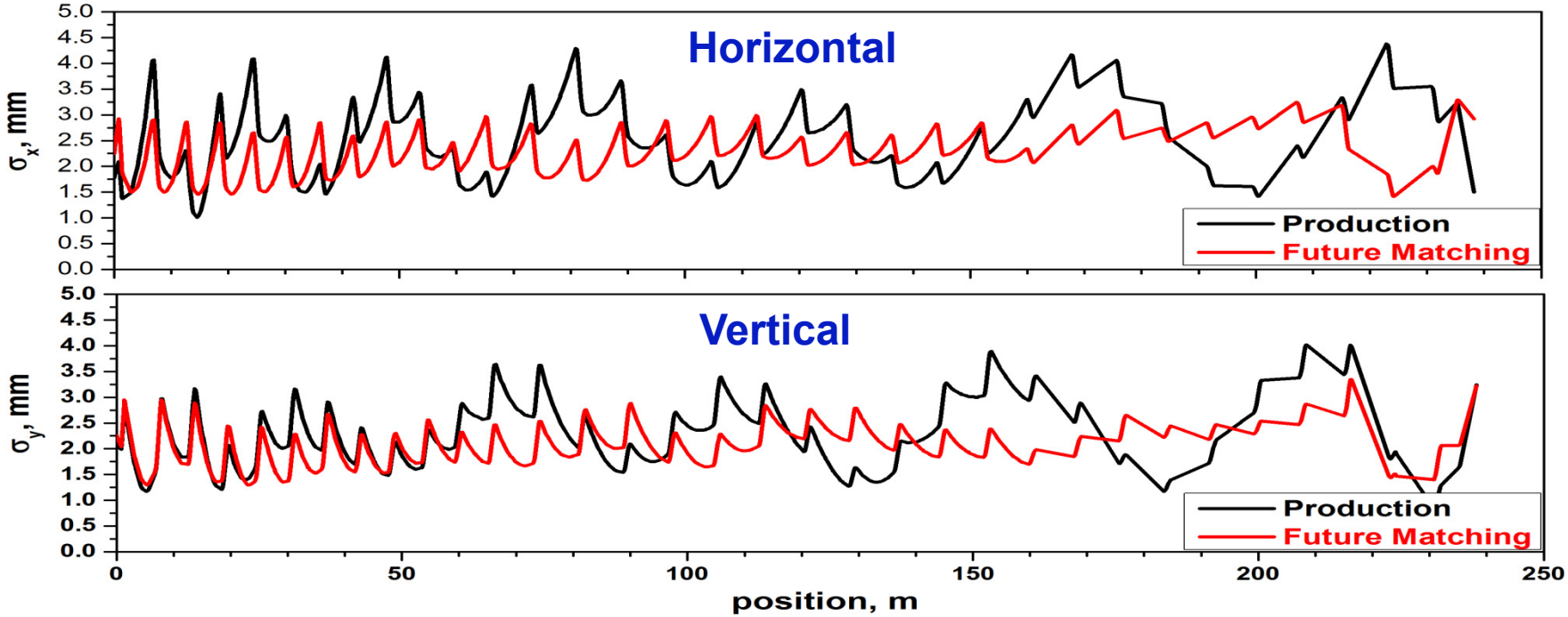
- Beam un-matched longitudinally
- Agreement is good even with space charge presence.

Transverse Twiss Analysis Results



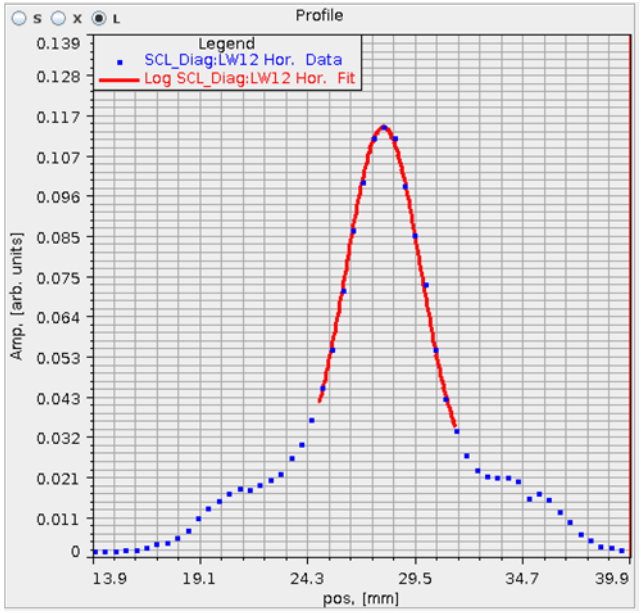
- Beam un-matched
- Peak current is 38 mA.
- Analysis was performed based on 8 LW stations measurements
- Procedure takes about 20 min
- RMS sizes calculated from the LW profiles
- XAL online model was used (beam envelop tracking)
- The model was initialized from phase scans data

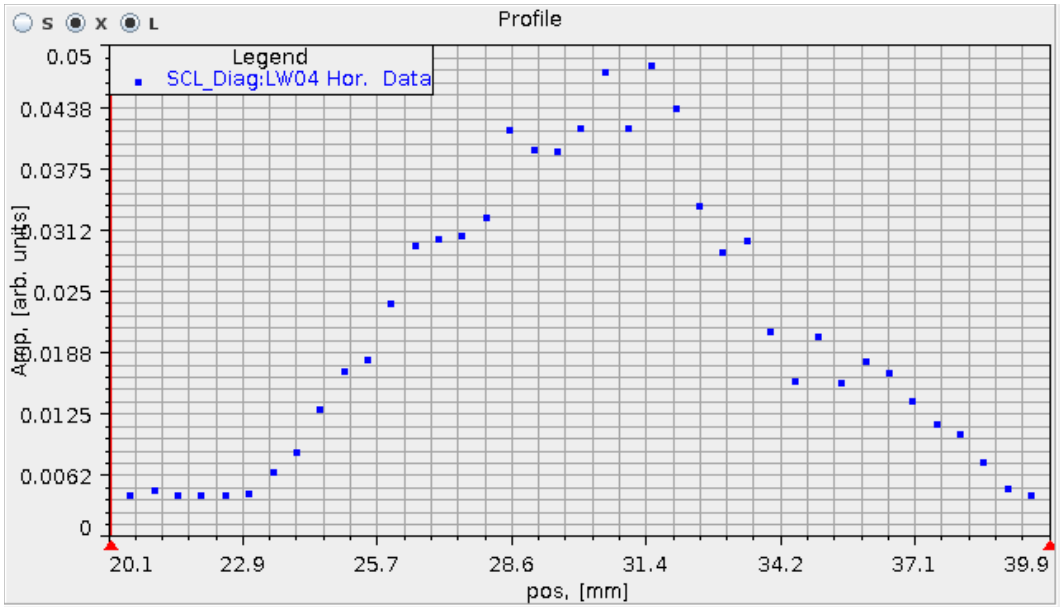
What We Want to Get



- We want to try matched beam
- That is an example how it could look like
- We want to check that we can control the beam sizes
- We hope to reduce beam loss

Laser Wire Profiles

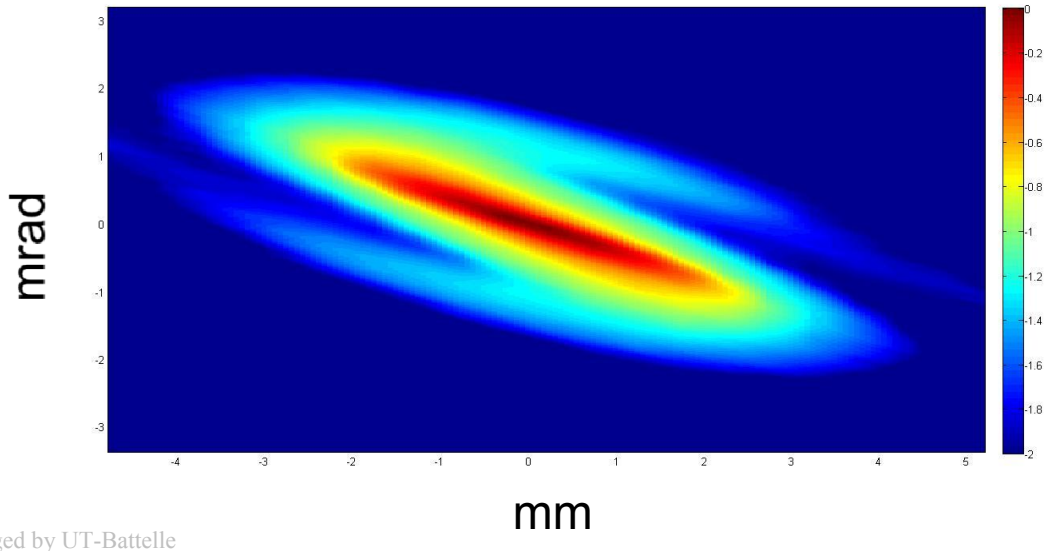




- Some distributions have big tails. These tails start to show up far upstream in DTL and CCL. The same type of profiles were seen at JPARC where tails were reduced by MEBT tuning.
- Some are asymmetrical.
- Some are noisy.
- It is difficult to estimate errors in RMS size calculations.

Model Based Tuning

- All previous attempts of the SCL beam matching failed. The possible causes
  - Unknown or wrong RF settings for the model
  - Unknown longitudinal Twiss
- At this moment we finished the integrated application to measure and to analyze the RF setting and initial Twiss
- The matching part is under development.
- We are going to do matching based on RMS sizes, but beam loss is defined not only by core through IBSt. The halo matching is different from the core matching.
- We have to pay attention to the warm linac tuning to reduce or to eliminate non-Gaussian tails.



X-X' Phases Space Density After SNS SCL. Spring, 2014

Color scale is logarithmic from .01 to 1

(courtesy of A. Aleksandrov)

Conclusions and Future Plans

- The SCL RF phase tuning procedures were improved
  - The accuracy of the phase setting were analyzed
  - The tuning time of 81 SCL cavities was reduced to 20 min
- The integrated application for the 3D initial Twiss measurement has been developed.
- The tuning of warm linac should be understood and should be improved to reduce tails of transverse profiles
- The matching part of this application is under development